Chapter 4. Materials Handling

This section was adapted from Section 13.2.4 of EPA's *Compilation of Air Pollutant Emission Factors (AP-42)*. Section 13.2.4 was last updated in January 1995.

4.1 Characterization of Source Emissions

Inherent in operations that use minerals in aggregate form is the handling and transfer of materials from one process to another (e.g., to and from storage). Outdoor storage piles are usually left uncovered, partially because of the need for frequent material transfer into or out of storage. Dust emissions occur at several points in the storage cycle, such as material loading onto the pile, disturbances by strong wind currents, and loadout from the pile. The movement of trucks and loading equipment in the storage pile area is also a substantial source of dust. Dust emissions also occur at transfer points between conveyors or in association with vehicles used to haul aggregate materials

4.2 Emissions Estimation: Primary Methodology[1-13]

The quantity of dust emissions from aggregate storage operations varies with the volume of aggregate passing through the storage cycle. Emissions also depend on the age of the pile, moisture content, and proportion of aggregate fines. When freshly processed aggregate is loaded onto a storage pile, the potential for dust emissions is at a maximum. Fines are easily disaggregated and released to the atmosphere upon exposure to air currents, either from aggregate transfer itself or from high winds. However, as the aggregate pile weathers the potential for dust emissions is greatly reduced. Moisture causes aggregation and cementation of fines to the surfaces of larger particles. Any significant rainfall soaks the interior of the pile, and then the drying process is very slow.

Table 4-1 summarizes measured moisture and silt content values for industrial aggregate materials. Silt (particles equal to or less than 75 micrometers [µm] in diameter) content is determined by measuring the portion of dry aggregate material that passes through a 200-mesh screen, using ASTM-C-136 method.[1]

Total dust emissions from aggregate storage piles result from several distinct source activities within the storage cycle:

1. Loading of aggregate onto storage piles (batch or continuous drop operations).
2. Equipment traffic in storage area.
3. Wind erosion of pile surfaces and ground areas around storage piles (see Chapter 9).
4. Loadout of aggregate for shipment or for return to the process stream (batch or continuous drop operations).

Table 4-1. Typical Silt and Moisture Contents of Materials at Various Industries[a]

Industry	No. of facilities	Material	Silt content (%)			Moisture content (%)		
			No. of samples	Range	Mean	No. of samples	Range	Mean
Iron and steel production	9	Pellet ore	13	1.3-13	4.3	11	0.64-4.0	2.2
		Lump ore	9	2.8-19	9.5	6	1.6-8.0	5.4
		Coal	12	2.0-7.7	4.6	11	2.8-11	4.8
		Slag	3	3.0-7.3	5.3	3	0.25-2.0	0.92
		Flue dust	3	2.7-23	13	1	–	7
		Coke breeze	2	4.4-5.4	4.9	2	6.4-9.2	7.8
		Blended ore	1	–	15	1	–	6.6
		Sinter	1	–	0.7	0	–	–
		Limestone	3	0.4-2.3	1.0	2	ND	0.2
Stone quarrying and processing	2	Crusted limestone	2	1.3-1.9	1.6	2	0.3-1.1	0.7
		Various limestone products	8	0.8-14	3.9	8	0.46-5.0	2.1
Taconite mining and processing	1	Pellets	9	2.2-5.4	3.4	7	0.05-2.0	0.9
		Tailings	2	ND	11	1	–	0.4
Western surface coal mining	4	Coal	15	3.4-16	6.2	7	2.8-20	6.9
		Overburden	15	3.8-15	7.5	0	–	–
		Exposed ground	3	5.1-21	15	3	0.8-6.4	3.4
Coal-fired power plant	1	Coal (as received)	60	0.6-4.8	2.2	59	2.7-7.4	4.5
Municipal solid waste landfills	4	Sand	1	–	2.6	1	–	7.4
		Slag	2	3.0-4.7	3.8	2	2.3-4.9	3.6
		Cover	5	5.0-16	9.0	5	8.9-16	12
		Clay/dirt mix	1	–	9.2	1	–	14
		Clay	2	4.5-7.4	6.0	2	8.9-11	10
		Fly ash	4	78-81	80	4	26-29	27
		Misc. fill materials	1	–	12	1	–	11

[a] References 1-10. ND = no data.

Either adding aggregate material to a storage pile or removing it usually involves dropping the material onto a receiving surface. Truck dumping on the pile or loading out from the pile to a truck with a front-end loader are examples of batch drop operations. Adding material to the pile by a conveyor stacker is an example of a continuous drop operation.

The quantity of particulate emissions generated by either type of drop operation, expressed as a function of the amount of material transferred, may be estimated using the following empirical expression:[11]

Metric Units

$$E = k(0.0016)\frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \text{ (kg/megagram [Mg])} \tag{1}$$

Nonmetric Units

$$E = k(0.0032)\frac{\left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \text{ (pound [lb]/ton)}$$

where:

E = emission factor
k = particle size multiplier (dimensionless)
U = mean wind speed (meters per second, m/s, or miles per hour, mph)
M = material moisture content (%)

The particle size multiplier in the equation, k, varies with aerodynamic particle size range, as follows:

Aerodynamic Particle Size Multiplier (k) for Equation (1)				
PM30	PM15	PM10	PM5	PM2.5
0.74	0.48	0.35	0.20	0.11

The equation retains the assigned quality rating of A if applied within the ranges of source conditions that were tested in developing the equation; see table below. Note that silt content is included, even though silt content does not appear as a correction parameter in the equation. While it is reasonable to expect that silt content and emission factors are interrelated, no significant correlation between the two was found during the derivation of the equation, probably because most tests with high silt contents were conducted under lower winds, and vice versa. It is recommended that estimates from Equation 1 be reduced one quality rating level if the silt content used in a particular application falls outside the following range:

Ranges of Source Conditions for Equation 1			
Silt content (%)	Moisture content (%)	Wind speed	
		m/s	mph
0.44 - 19	0.25 - 4.8	0.6 - 6.7	1.3 - 15

For Equation 1 to retain the quality rating of A when applied to a specific facility, reliable correction parameters must be determined for the specific sources of interest. The field and laboratory procedures for aggregate sampling are given in Reference 3. In the event that site-specific values for correction parameters cannot be obtained, the appropriate mean values from Table 4-1 may be used, but the quality rating of the equation is reduced by one letter.

For emissions from trucks, front-end loaders, dozers, and other vehicles traveling between or on piles, it is recommended that the equations for vehicle traffic on unpaved surfaces be used (see Chapter 6). For vehicle travel between storage piles, the silt value(s) for the areas among the piles (which may differ from the silt values for the stored materials) should be used.

Worst-case emissions from storage pile areas occur under dry, windy conditions. Worst-case emissions from materials-handling operations may be calculated by substituting into the equation appropriate values for aggregate material moisture content and for anticipated wind speeds during the worst case averaging period, usually 24 hours. A separate set of nonclimatic correction parameters and source extent values corresponding to higher than normal storage pile activity also may be justified for the worst-case averaging period.

4.3 Demonstrated Control Techniques

Watering and the use of chemical wetting agents are the principal means for control of emissions from materials handling operations involving transfer of bulk minerals in aggregate form. The handling operations associated with the transfer of materials to and from open storage piles (including the traffic around piles) represent a particular challenge for emission control. Dust control can be achieved by: (a) source extent reduction (e.g., mass transfer reduction), (b) source improvement related to work practices and transfer equipment such as load-in and load-out operations (e.g., drop height reduction, wind sheltering, moisture retention)), and (c) surface treatment (e.g., wet suppression).

In most cases, good work practices which confine freshly exposed material provide substantial opportunities for emission reduction without the need for investment in a control application program. For example, loading and unloading can be confined to leeward (downwind) side of the pile. This statement also applies to areas around the pile as well as the pile itself. In particular, spillage of material caused by pile load-out and maintenance equipment can add a large source component associated with traffic-entrained dust. Emission inventory calculations show, in fact, that the traffic dust component may easily dominate over emissions from transfer of material and wind erosion. The prevention of spillage and subsequent spreading of material by vehicles traversing the area is essential to cost-effective emission control. If spillage cannot be prevented because of the need for intense use of mobile equipment in the storage pile area, then regular cleanup should be employed as a necessary mitigative measure.

Fugitive emissions from aggregate materials handling systems are frequently controlled by wet suppression systems. These systems use liquid sprays or foam to suppress the formation of airborne dust. The primary control mechanisms are those that prevent emissions through agglomerate formation by combining small dust particles with larger aggregate or with liquid droplets. The key factors that affect the degree of agglomeration and, hence, the performance of the system are the coverage of the material by the liquid and the ability of the liquid to "wet" small particles. There are two types of wet suppression systems—liquid sprays which use water or water/surfactant mixtures as the wetting agent and systems which supply foams as the wetting agent.

Liquid spray wet suppression systems can be used to control dust emissions from materials handling at conveyor transfer points. The wetting agent can be water or a combination of water and a chemical surfactant. This surfactant, or surface active agent, reduces the surface tension of the water. As a result, the quantity of liquid needed to achieve good control is reduced.

Watering is also useful to reduce emissions from vehicle traffic in the storage pile area. Continuous chemical treating of material loaded onto piles, coupled with watering or treatment of roadways, can reduce total particulate emissions from aggregate storage operations by up to 90%.[12]

Table 4-2 presents the control efficiency achieved by increasing the moisture content of a material by a factor of two above its normal "dry" state using a continuous water spray at a conveyor storage point. The efficiency of 62% is calculated by utilizing the AP-42 emission factor equation from Equation 1, which contains a correction term for moisture content.

Table 4-2. Control Efficiencies for Control Measures for Materials Handling

Control measure	PM10 control efficiency	References/comments
Continuous water spray at conveyor transfer point	62%	AP-42 emission factor equation for materials handling due to increasing soil moisture from 1% to 2%.

4.4 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. Regulatory formats specify the threshold source size that triggers the need for control application. Example regulatory formats for several local air quality agencies in the WRAP region are presented in Table 4-3. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: http://www.maricopa.gov/envsvc/air/ruledesc.asp

(Note: The Clark County website did not include regulatory language specific to materials handling at the time this chapter was written.)

4.5 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations. An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Table 4-3. Example Regulatory Formats for Materials Handling

CAPCOA				Maricopa County, AZ			
Control Measure	Goal	Threshold	Agency	Control Measure	Goal	Threshold	Agency
Establishes wind barrier and watering or stabilization requirements and bulk materials must be stored according to stabilization definition and outdoor materials covered	Limit visible dust emissions to 20% opacity		SJVAPCD Rule 8031 11/15/2001	Watering, dust suppressant (when loading, stacking, etc.); cover with tarp, watering (when not loading, etc.); wind barriers, silos, enclosures, etc.	Limit VDE to 20% opacity; stabilize soil	For storage piles with >5% silt content, 3ft high, >/=150 sq ft; work pracs for stacking, loading, unloading, and when inactive; soil moisture content min 12%; or at least 70% min for optimum soil moisture content; 3 sided enclosures, at least equal to pile in length, same for ht, porosity </=50%	Maricopa County Rule 310 04/07/2004
Best available control measures: wind sheltering, watering, chemical stabilizers, altering load-in/load-out procedures, or coverings	Prohibits visible dust emissions beyond property line and limits upwind/downwind PM10 differential to 50 ug/m3		SCAQMD Rule 403 12/11/1998				
				Watering, clean debris from paved roads and other surface after demolition	Stabilize demolition debris and surrounding area; establish crust and prevent wind erosion	Immediately water and clean-up after demolition	Maricopa County Rule 310 04/07/2004
Additional bulk material control requirements for Coachella Valley	Control bulk material emissions	Coachella Valley	SCAQMD Rule 403.1 1/15/1993	Utilization of dust suppressants other than water when necessary; prewater; empty loader bucket slowly	Prevent wind erosion from piles; stabilize condition where equip and vehicles op	Bulk material handling for stacking, loading, and unloading; for haul trucks and areas where equipment op	Maricopa County Rule 310 04/07/2004

Table 4-4 summarizes the compliance tools that are applicable to materials handling.

Table 4-4. Compliance Tools for Materials Handling

Record keeping	Site inspection/monitoring
Site map; work practices and locations; material throughputs; type of material and size characterization; typical moisture content when fresh; vehicle/equipment disturbance areas; material transfer points and drop heights; spillage and cleanup occurrences; wind fence/enclosure installation and maintenance; dust suppression equipment and main-tenance records; frequencies, amounts, times, and rates for watering and dust suppressants; meteorological log.	Observation of material transfer operations and storage areas (including spills), operation of wet suppression systems, vehicle/ equipment operation and disturbance areas; surface material sampling and analysis for silt and moisture contents; inspection of wind sheltering including enclosures; real-time portable monitoring of PM; observation of dust plume opacities exceeding a standard.

4.6 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for materials handling. A sample cost-effectiveness calculation is presented below for a specific control measure(continuous water spray at conveyor transfer point) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for construction and demolition, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Materials Handling (Conveyor Transfer Point)

Step 1. Determine source activity and control application parameters.

Material throughput (tons/hr)	25
Operating cycle (hr/day)	12
Number of workdays/wk	6
Number of workdays/yr	312
Number of transfer points	1
Control Measure	Water spray located at conveyor transfer point
Control application/frequency	Continuous
Economic Life of Control System (yr)	10
Control Efficiency (from emission factor equation; see step 2)	62%

The material throughput, operating cycle, number of workdays a week, number of transfer points, and economic life are assumed values for illustrative purposes. The number of workdays per year are calculated by multiplying the number of workdays per week by 52 weeks per year. A water spray located at conveyor transfer points has been chosen as the applied control measure. The control application/frequency and control efficiency are derived from the equation in Section 13.2.4 of AP-42 (i.e., Equation 1) based on the increase in moisture content.

Step 2. Calculate Emission Factor. The PM2.5 and PM10 emission factors are calculated from the AP-42 equation utilizing the appropriate correction parameters.

$$\mathbf{E=k(0.0032)*((U/5)^{1.3}/(M/2)^{1.4})}$$

k—PM2.5 (dimensionless)	0.11
k—PM10 (dimensionless)	0.35
U—mean wind speed (mph)	6
M—moisture content (%)	1

- E_{PM10} = 0.0038 lb/ton
- $E_{PM2.5}$ = 0.0012 lb/ton

Step 3. Calculate Uncontrolled PM Emissions. The emission factors (calculated in Step 2) are multiplied by the material throughput, operating cycle, and workdays per year (all under activity data) and then divided by 2,000 lbs to compute the annual emissions in tons per year, as follows:

Annual emissions = (Emission Factor x Material Throughput x Operating Cycle x Workdays/yr)/2,000

- Annual PM10 Emissions = (0.004 x 25 x 12 x 312)/2000 = 0.175 tons
- Annual PM2.5 Emissions = (0.001 x 25 x 12 x 312)/2000 = 0.055 tons

Step 4. Calculate Controlled PM Emissions. The uncontrolled emissions (calculated in Step 3) are multiplied by the percentage that uncontrolled emissions are reduced, as follows:

Controlled emissions = Uncontrolled emissions x (1 – Control Efficiency), where CE = 62% (as seen under activity data)

For this example, we have selected a water spray at a conveyor transfer point as our control measure. Based on a control efficiency estimate of 62%, the annual emissions estimate is calculated to be:

Annual Controlled PM10 emissions = (0.175 tons) x (1 –0.62) = 0.066 tons
Annual Controlled PM2.5 emissions = (0.055 tons) x (1 –0.62) = 0.021 tons

Step 5. Determine Annual Cost to Control PM Emissions.

Capital costs ($)	16,000
Operating/Maintenance costs ($)	8,000
Overhead costs ($)	4,000
Enforcement/Compliance costs ($)	200
Annual Interest Rate	3%
Capital Recovery Factor	0.12
Total Cost ($)	28,200
Annualized Cost ($/yr)	14,076

The Capital costs, the Operating/Maintenance costs, and the Enforcement/Compliance costs are default values determined from current sources (e.g. Sierra Research, 2003).[14]

The Overhead costs are typically one-half of the Operating/Maintenance costs
Overhead costs = $8,000/2 = $4,000.

The Annual Interest Rate (AIR) is based on the most up to date information and sources.

The Capital Recovery Factor (CRF) is figured by multiplying the Annual Interest Rate by 1 plus the AIR, raised to the exponent of the Economic life of the control system . Then divide by 1 plus the AIR to the Economic life minus 1, as follows:

$$\text{Capital Recovery Factor} = \text{AIR x } (1+\text{AIR})^{\text{Economic life}} / (1+\text{AIR})^{\text{Economic life}} - 1$$

$$\text{Capital Recovery Factory} = 3\% \text{ x } (1+3\%)^{10} / (1+3\%)^{10} - 1 = 0.12$$

The Total Cost is the sum of the Capital costs, Operating/Maintenance costs, Overhead costs, and the Enforcement/Compliance costs:

Total Cost = Capital costs + Operating/Maintenance costs + Overhead + Enforcement/Compliance costs

Total Cost = 16,000 + 8,000 + 4,000 + 200 = $28,200

The Annualized Cost is calculated by adding the product of the Capital Recovery Factor by the Capital costs with the Operating/Maintenance costs and the Overhead costs and the Enforcement/Compliance costs:

Annualized Cost = (CRF x Capital costs) + Operating/Maintenance + Overhead costs + Enforcement/Compliance costs

Annualized Cost = (0.12 x 16,000) + 8,000 + 4,000 + 200 = $14,076

Step 6. Calculate Cost-effectiveness. Cost-effectiveness is calculated by dividing the annualized cost by the emissions reduction. The emissions reduction is determined by subtracting the controlled emissions from the uncontrolled emissions:

Cost-effectiveness = Annualized Cost/ (Uncontrolled emissions – Controlled emissions)

Cost-effectiveness for PM10 emissions = $14,076/ (0.175– 0.066) = $130,000/ton
Cost-effectiveness for PM2.5 emissions = $14,076/ (0.055– 0.021) = $411,000/ton

4.7 References

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14. Sierra Research, 2003. *Final BACM Technological and Economic Feasibility Analysis*, prepared for the San Joaquin Valley Unified APCD, March.